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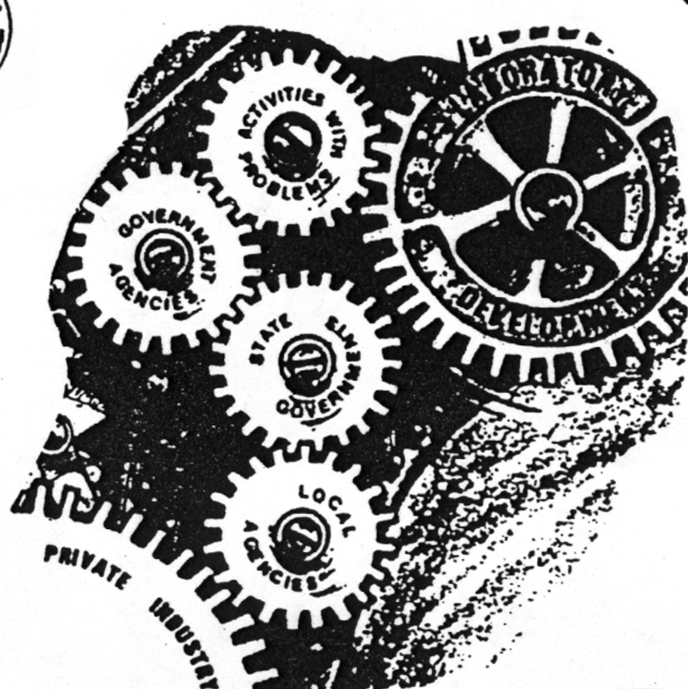

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EFFECT OF COLD WEATHER ON PRODUCTIVITY

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Abstract

A "cold environment factor" scheme, based on data from various sources which indicate the apparent effect of cold weather characteristics on manual and equipment task efficiency, has been developed to estimate the expected effort, in terms of required time, for performing tasks in any cold environment condition.

Introduction

Almost any kind of outside work requires more time and effort when performed in a cold environment, the principal characteristics of that environment being low temperature, wind and precipitation (snowfall).

Comparative field tests, where the only variables are the environmental conditions, while the tasks, equipment and personnel remain the same, would provide relatively reliable data on the effects of the environment. In the absence of such data, it is necessary to use the available results of various surveys from the construction industry and the military, which indicate the relative efficiency of people and equipment while functioning in selected cold environment conditions [Refs. 1–13]. The following analysis represents an initial attempt to predict the influence of cold environment on outdoor work by introducing a "cold environment factor," the inverse of efficiency.

Effect of temperature, wind and snowfall

Figure 1 shows the typical range of efficiency for construction or repair type of manual and equipment tasks as a function of air temperature. The upper curve of the manual task envelope in Figure 1 could be considered the upper efficiency level, the lower curve representing the lower efficiency level. Below –40°F any manual work becomes extremely difficult, regardless of motivation or experience. Also, at this temperature construction equipment are rarely operated. Data from surveys show that the variation in efficiency of a particular piece of equipment or a task at a specific weather condition is much wider than the variation between several different types of equipment. Therefore, at this time, no distinction is made between specific types of tasks or equipment.

There is a general lack of published data on the effects of wind. For manual tasks, the wind influence can be expressed by the "windchill" factor which combines the effects of both temperature and wind on humans. The general empirical equation, developed by Paul Siple 50 years ago in Antarctica [Ref. 14], is:

$$T_e = 91.4 - \left[\left(0.288\sqrt{V} + 0.45 - 0.019V\right)\left(91.4 - T\right)\right]$$

where T_e = equiv. windchill temp. (°F)
V = wind speed (mph)
T = air temperature (°F)

The equation is applicable only for the wind speed range between 5 and 50 mph. For the range of $5<V<30$, the windchill can be computed more conveniently by:

$$T_e = \log V\ (0.59T - 54.2) + 0.59T + 37.2$$

The relationship between windchill and wind speed at various air temperatures is shown in Figure 2.

The windchill factor can not be applied to equipment. Available data show equipment efficiency to be in the 80 to 90% range at a wind speed of 30 mph, requiring interpolation for lower wind speeds.

The effect of snowfall intensity (which incorporates visibility, accumulation problems, etc.) on manual and equipment tasks is shown in Figure 3.

Field tests of various tasks under actual cold environment conditions are needed to indicate whether or not other factors besides temperature, wind speed and snowfall intensity have to be considered in establishing the expected efficiency of performing a task in cold weather. Some conditions such as slipperiness, for example, can be controlled and, therefore, are not considered at this stage.

The cold environment factor

To express the relative effort of performing a construction or a repair task in cold weather, it is more convenient to use a factor that is the inverse of efficiency ($F = 1/E$), the base value ($F = 1$) representing the effort required to perform the task under ideal weather conditions (temperature 50 to 60°F for manual tasks, 40°F or above for equipment tasks, no wind or precipitation). As work efficiency decreases with the adversity of weather conditions, the "cold environment factor" increases, giving the value by which the optimum work effort (in terms of time) would have to be multiplied to determine the length of time required to perform the task in a particular cold environment condition.

From the efficiency data, nomographs have been constructed showing the "cold environment factors" for manual (F_m) and equipment tasks (F_e) at any temperature, wind and snowfall condition.

The factor for manual tasks is shown for both the lower and upper efficiency levels (Figures 4 and 5, respectively). For equipment performance, the mean values from Figure 1 were used to construct the nomograph (Figure 6). The factors for the manual (upper efficiency level) and equipment tasks for various environmental conditions are shown in Table 1.

The example shown in Figures 4 through 6 (T = 20°F, V = 20 mph, P = moderate snowfall) indicates that, for this condition, the standard time for each manual task would have to be multiplied by 2.2, assuming upper efficiency level (or by 3.6 for the lower efficiency level), and the time for any equipment task by 1.3.

Since the available equipment efficiency data cover quite a range of equipment types and tasks (not listed here), it should be understood that, at this point, the "cold environment factors" shown here are, at best, tentative typical values, representing the average of a wide variety of equipment operations. To some degree, this situation applies also to the factors for manual tasks.

A typical military application of the "cold environment factor" scheme would be, for example, in the development of rapid runway repair procedures, where time is a critical element. When Program Evaluation Review Technique (PERT) diagrams are eventually developed showing the "critical path" for repair procedures during ideal weather conditions, it will be necessary to predict the expected cold environment effects on the schedule. The introduction of the "cold environment factors" will result in a stretched PERT diagram, an important consideration being the effect on the "critical path."

An example of this is illustrated in Figure 7, which compares the PERT diagram of an U.S. Air Force rapid runway repair procedure in ideal weather conditions [Ref. 15] with the PERT diagram resulting from introducing the appropriate manual and equipment task "cold environment factors" (upper efficiency level) for a sample cold weather condition. The ratio of the estimated required time in cold weather (415 min) and the scheduled time in ideal weather (230 min) results in a factor of 1.8. That is, this particular task, which required approximately 4 hours in ideal weather, would probably require approximately 7 hours when done during a snowy, windy day at a temperature of 20°F, assuming performance at a high motivation and efficiency level.

At this stage, the cold environment factor scheme, described here, is merely a first attempt to predict the likely effect of a cold environment on construction and repair efforts. Actual field tests are required to determine if and how the "cold environment factors" need to be modified.

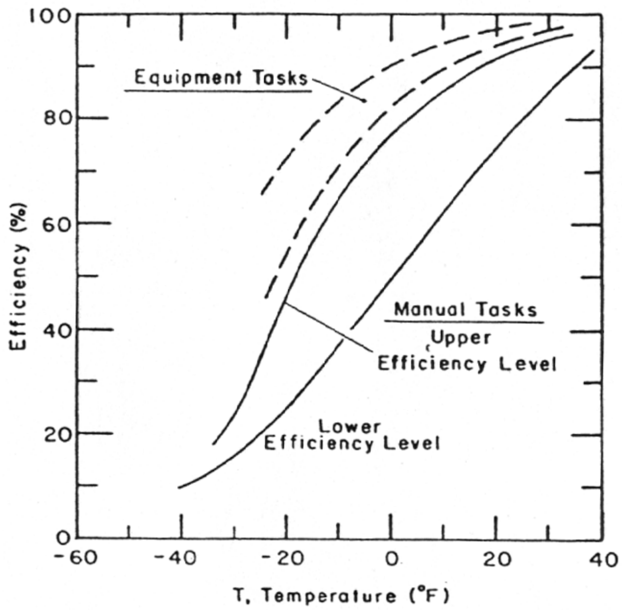

Figure 1. The effect of temperature on manual and equipment tasks.

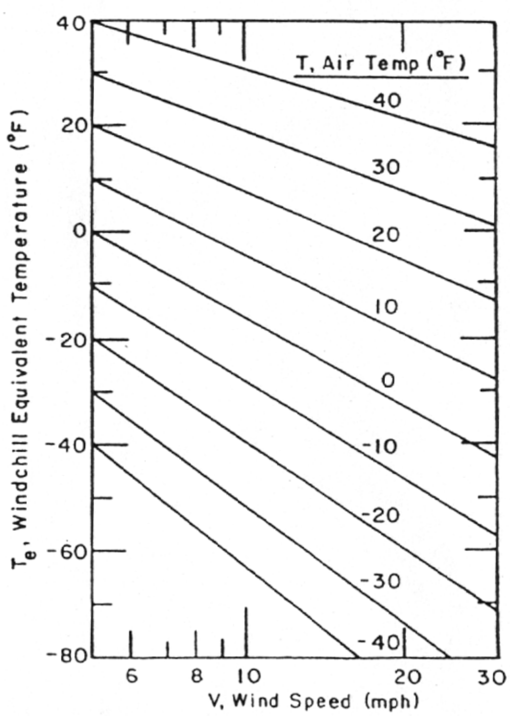

Figure 2. Windchill equivalent temperature.

Table 1. Cold environment factors in various weather conditions.

Environmental Conditions			Cold Environment Factor	
T (°F)	Wind (mph)	Snow-fall	F_m (Manual)	F_e (Equipm.)
20	<5	0	1.1	1.05
20	<5	L	1.2	1.10
20	<5	M	1.7	1.24
20	<5	H	2.7	1.40
10	<5	0	1.2	1.09
10	<5	L	1.3	1.14
10	<5	M	1.8	1.29
10	<5	H	3.0	1.45
0	<5	0	1.3	1.16
0	<5	L	1.5	1.22
0	<5	M	2.0	1.37
0	<5	H	3.3	1.54
−10	<5	0	1.5	1.23
−10	<5	L	1.7	1.34
−10	<5	M	2.3	1.51
−10	<5	H*	3.7	1.70
−20	<5	0	2.0	1.54
−20	<5	L	2.2	1.62
−20	<5	M*	2.7	1.82
−20	<5	H*	4	2.05
20	20	0	1.4	1.10
20	20	L	1.6	1.16
20	20	M	2.2	1.30
20	20	H	3.5	1.47
10	20	0	2.0	1.14
10	20	L	2.2	1.20
10	20	M	2.6	1.35
10	20	H	4	1.52
0	20	0	>5	1.22

*Snowfall of this intensity at this temperature very unlikely.

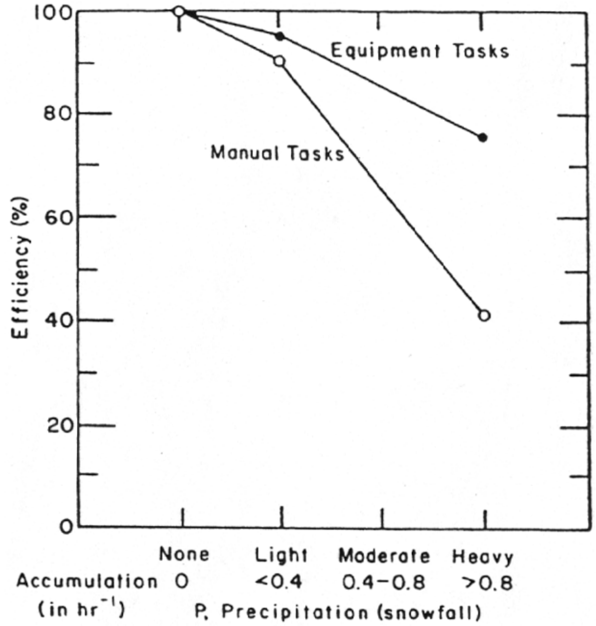

Figure 3. The effect of snowfall on manual and equipment tasks.

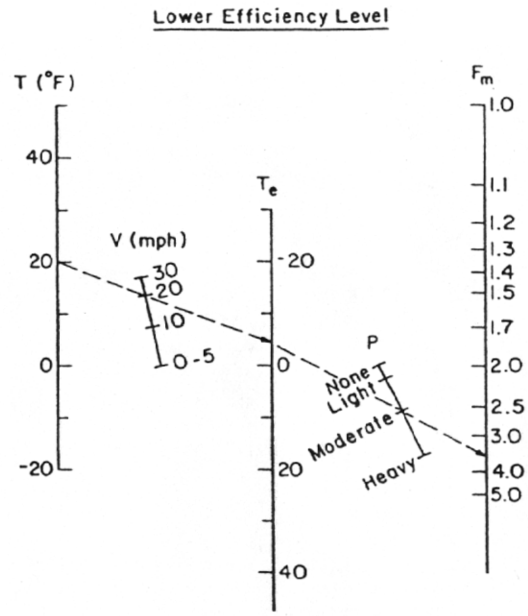

Figure 4. Nomograph for estimating cold environment factor for manual tasks (lower efficiency level).

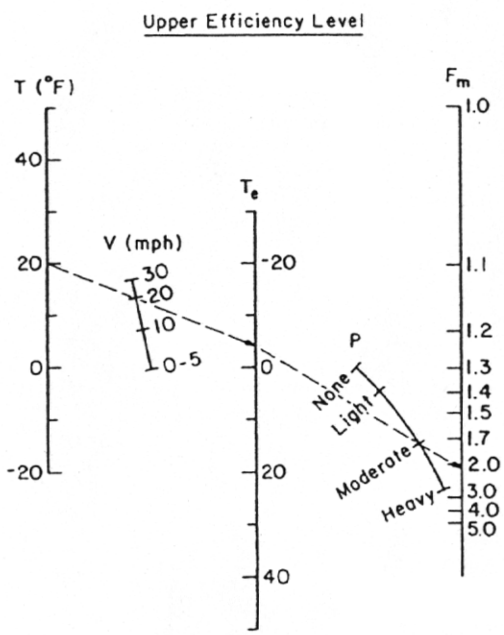

Figure 5. Nomograph for estimating cold environment factor for manual tasks (upper efficiency level).

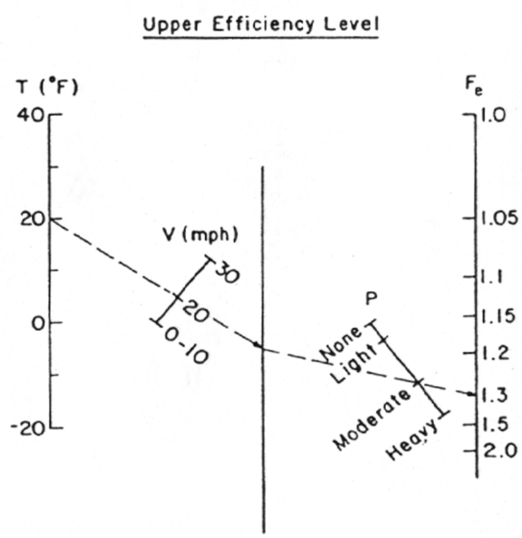

Figure 6. Nomograph for estimating cold environment factor for equipment tasks.

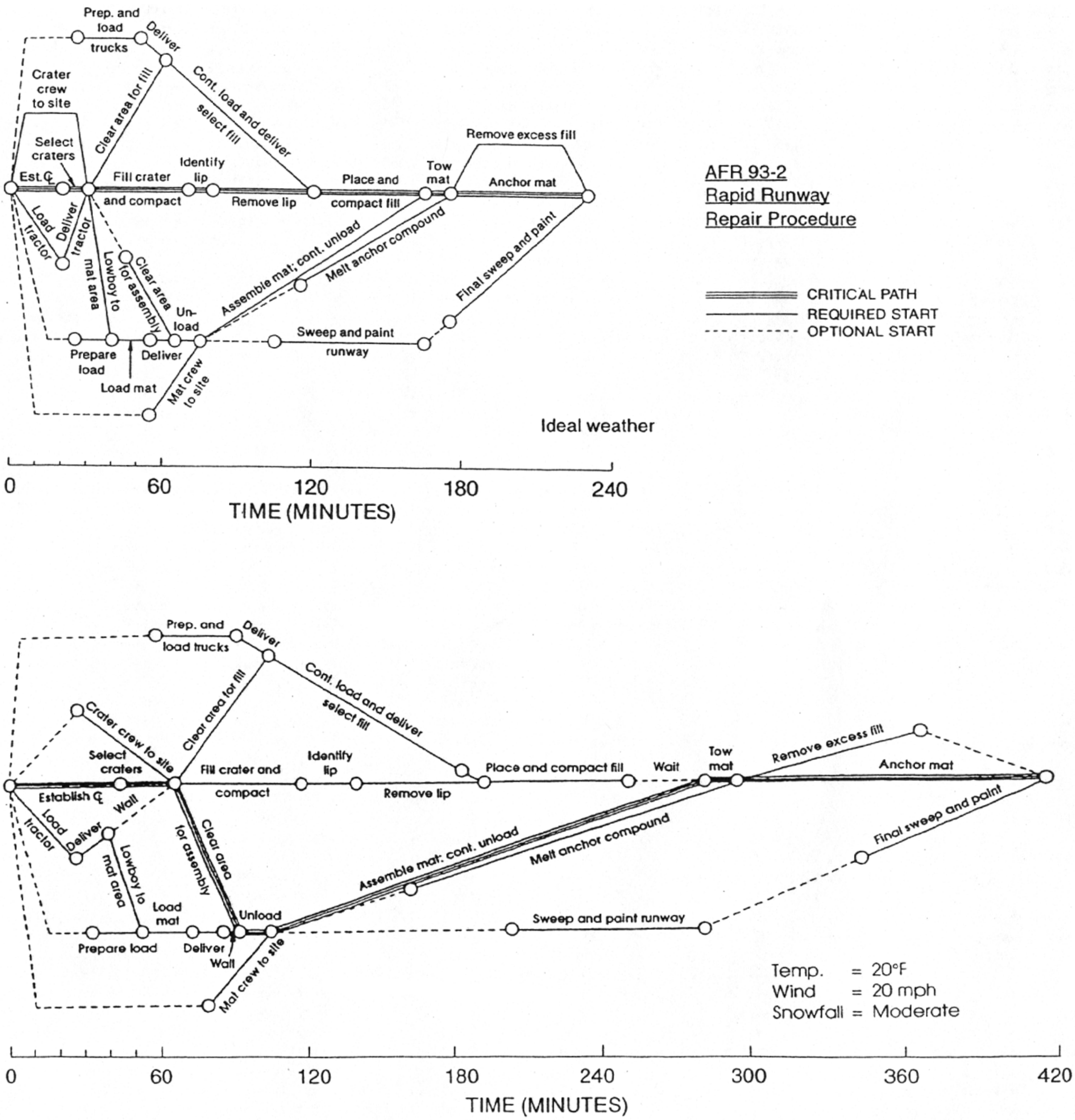

Figure 7. PERT diagrams for a runway repair procedure in ideal and cold weather.

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